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Project Report

LTP-35

Air Breakdown Initiated by Particles in an HF Laser Beam

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28 October 1976

Prepared for the Defense Advanced Research Projects Agency
under Electronic Systems Division Contract F19628-76-C-0002 by

Lincoln Laboratory

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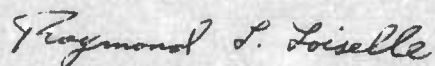
The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology. This work was sponsored by the Defense Advanced Research Projects Agency under Air Force Contract F19628-76-C-0002 (ARPA Order 600).

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FOR THE COMMANDER

A handwritten signature in cursive script that reads "Raymond L. Loiselle".

Raymond L. Loiselle, Lt. Col., USAF
Chief, ESD Lincoln Laboratory Project Office

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AIR BREAKDOWN INITIATED BY PARTICLES
IN AN HF LASER BEAM

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Group 51

PROJECT REPORT LTP-35

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ABSTRACT

Thresholds were measured for air breakdown initiated by particles in a 3.5 μsec , 2.9 μm laser beam. The pulsed chemical laser at Boeing Aerospace Corporation was used for these studies. The thresholds for 50 μm diameter graphite, NaCl, Al_2O_3 particles and 10 μm and 30 μm quartz fibers were found to be factors of three to five higher than the comparable thresholds for 10.6 μm lasers. The material dependence for the threshold was found to differ from that for short pulse 10.6 μm breakdown. The radial plasma growth rate was measured and found to be approximately equal to the growth rate at 10.6 μm for an intensity of $3 \times 10^7 \text{ W/cm}^2$.

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AIR BREAKDOWN INITIATED BY PARTICLES IN AN HF LASER BEAM

I. INTRODUCTION

The intensity thresholds for air breakdown initiated by particles in a 10.6 μm laser beam have been found to decrease with increasing laser pulse length.^{1,2,3} Values as low as $2 \times 10^6 \text{ W/cm}^2$ for 100 μsec pulse have been reported. There exists no comprehensive theory which can quantitatively explain these so called "long pulse" breakdown data. There are, however, fairly good theoretical descriptions^{4,5} for laser induced aerosol breakdown data^{6,7} at short pulse lengths ($\tau \lesssim 200 \text{ nsec}$). The dependence of aerosol breakdown thresholds on wavelength has been studied experimentally^{7,8} but only for short pulse lengths ($\tau \lesssim 150 \text{ nsec}$). These data indicated an approximate λ^{-2} scaling for the short pulse aerosol breakdown thresholds.

This report gives the results of a three-week experimental study of aerosol breakdown for long pulse, short wavelength lasers. The objectives of the experiment were to establish a data base for the wavelength dependence of long pulse aerosol breakdown and to measure the radial growth rate of the breakdown plasma. Use of the pulse chemical laser facilities⁹ at Boeing Aerospace Corporation, Seattle, Washington, was purchased from 12-30 July 1976. A total of approximately 186 laser shots were obtained during the experiment. All the device performance characteristics met or exceeded the minimum requirements specified in the contract.

II. EXPERIMENTAL PROCEDURE

The experimental set up is shown in Figure 1. A pulsed HF laser⁹

operating in a stable cavity configuration produced an approximately 5"x5" beam with lines from 2.75 to 3.1 μm ($\bar{\lambda} \approx 2.9 \mu\text{m}$). The beam was brought to a focus with a 6" diameter, 12" focal length CaF_2 lens (L1). A similar lens (L2) was used to recollimate the beam. The input beam energy was monitored with a BaTiO_3 detector (E1) which was calibrated against an RdF calorimeter placed just after lens L1. The transmitted energy was monitored with a BaTiO_3 detector (E2). The incident and transmitted pulse shapes were monitored with fast pyroelectric Molelectron detectors (P1 and P2). A photo diode (PD) measured the light emission from the breakdown region. A HeNe beam was used for alignment via a removable mirror (RM). Time-resolved data on the plasma growth rate were obtained with a two-frame image converter camera system. The difference in frame times for the two cameras (ICC1 and ICC2) was $\approx 500 \text{ nsec}$.

The insert in Figure 1 shows the setup used for the measurement of the beam profile at focus. Lens L2 was repositioned to provide a magnified ($\times 2.5$) image of the focus. A 32-element pyroelectric array (Laser Precision Corporation) placed at this image plane was used for the beam profile measurements.

The optical components BS1, L1, L2, and W2 were made of CaF_2 , the remaining components (A, L3, L4, BS2, L5, L6 and W1) were made of GE 125 quartz.

The focal volume of lens L1 was seeded with large aerosols (50 μm diameter) at a density such that there were approximately 50 particles present in the focal volume on each shot. For the quartz fiber thresholds, single fibers were suspended at the beam focus. The beam was attenuated with a

series of coated attenuators (A). Threshold was defined as the intensity for 50% probability of breakdown.

III. RESULTS

The beam profiles obtained from array measurements are shown in Figure 2. The array gave a one dimensional cut through the beam at a given y position for each shot. The resolution was 0.4 mm in the x direction and 0.8 mm in the y direction. The z axis in Figure 2 gives the energy fluence per joule. The peak value at the focus was approximately 6.25 cm^{-2} . This corresponds to an effective spot area (energy divided by peak energy fluence) $\bar{A} \approx 0.16 \text{ cm}^2$.

The laser pulse shape is shown in Figure 3. The effective pulse length (energy divided by peak power) $\bar{\tau} \approx 3.5 \text{ } \mu\text{sec}$.

Breakdown thresholds were obtained for 50 μm carbon (graphite), NaCl, Al_2O_3 particles and for 10 μm and 30 μm quartz fibers. Figure 3 shows a comparison of the incident and transmitted laser power and the light emitted from the breakdown. Breakdown was characterized by a rapid attenuation of the laser beam and an exponential growth of the emitted light.

The threshold data are summarized in Table 1. The values of intensity correspond to the peak value at focus which gave a 50% probability of breakdown. The estimated uncertainty for these data is $\approx \pm 20\%$. Also shown in the table are the estimated threshold values for 10.6 μm breakdown at 3.5 μsec pulse lengths. These were obtained by extrapolating published data^{1,2,3} to a 3.5 μsec pulse and have an uncertainty of $\approx \pm 30\%$.

TABLE I

SUMMARY OF EXPERIMENTAL RESULTS

Particle	Breakdown Threshold (W/cm^2)	
	$\lambda=2.9 \mu\text{m}$ $\tau=3.5 \mu\text{sec}$	$\lambda=10.6 \mu\text{m}$ estimated for $\tau=3.5 \mu\text{sec}$
50 μm Carbon (graphite)	8×10^7 ($\pm 20\%$)	1.5×10^7 ($\pm 30\%$)
50 μm NaCl	2.4×10^7 ($\pm 20\%$)	8×10^6 ($\pm 30\%$)
50 μm Al_2O_3	3.2×10^7 ($\pm 20\%$)	8×10^6 ($\pm 30\%$)
10 μm quartz Fiber	4.5×10^7 ($\pm 20\%$)	1.5×10^7 ($\pm 30\%$)
30 μm quartz Fiber	3.4×10^7 ($\pm 20\%$)	10^7 ($\pm 30\%$)
Growth Rate (cm/sec) for $I=3 \times 10^7 \text{ W}/\text{cm}^2$		
$\lambda=2.9 \mu\text{m}$		$\lambda=10.6 \mu\text{m}$
2.5×10^5 ($\pm 20\%$)		1.75×10^5 ($\pm 20\%$)

The plasma growth rate was measured with the two frame image converter camera system shown in Figure 1. For these measurements a 150 μm wire inserted in the beam, with axis parallel to the camera's optical axis, was used to ignite the breakdowns. Estimates of the radial growth rates for particle-initiated breakdowns were also made based on the cutoff rate of the transmitted beam. These were found to be consistent with the wire induced breakdown growth rates. The measured growth rate is shown in Table 1 together with 10.6 μm growth rate³ at the same intensity.

IV. CONCLUSIONS

The measured breakdown thresholds at $\lambda=2.9 \mu\text{m}$ were consistently higher by factors of 3 to 5 than the corresponding 10.6 μm data. Although it is difficult to make a quantitative comparison, because of the differences in laser pulse shapes and the measurement uncertainties, it appears that the threshold for $\tau=3.5 \mu\text{sec}$ scales approximately as λ^{-1} . This is to be compared to short pulse ($\tau=150 \text{ nsec}$) results^{7,8} where for large particles it was found that the threshold scaled approximately as λ^{-2} .

The thresholds measured in this experiment had a different material dependence than those for short pulse 10.6 μm experiments.⁶ For example, for ($\lambda=2.9 \mu\text{m}$, $\tau=3.5 \mu\text{sec}$) the carbon threshold was a factor three higher than that for NaCl, while for ($\lambda=10.6 \mu\text{m}$, $\tau=150 \text{ nsec}$) the NaCl threshold was a factor of two higher than that for carbon.

The plasma growth rate measured for $\lambda=2.8 \mu\text{m}$ was comparable to the value at 10.6 μm .

The breakdown threshold results suggest that different physical processes are involved in long and short pulse breakdown.

ACKNOWLEDGMENTS

The authors wish to thank the technical staff at Boeing Aerospace Corporation for their helpful assistance and cooperation during this work. Special thanks are due to R. B. Hall, D. B. Nichols, L. Alexander and D. Botz.

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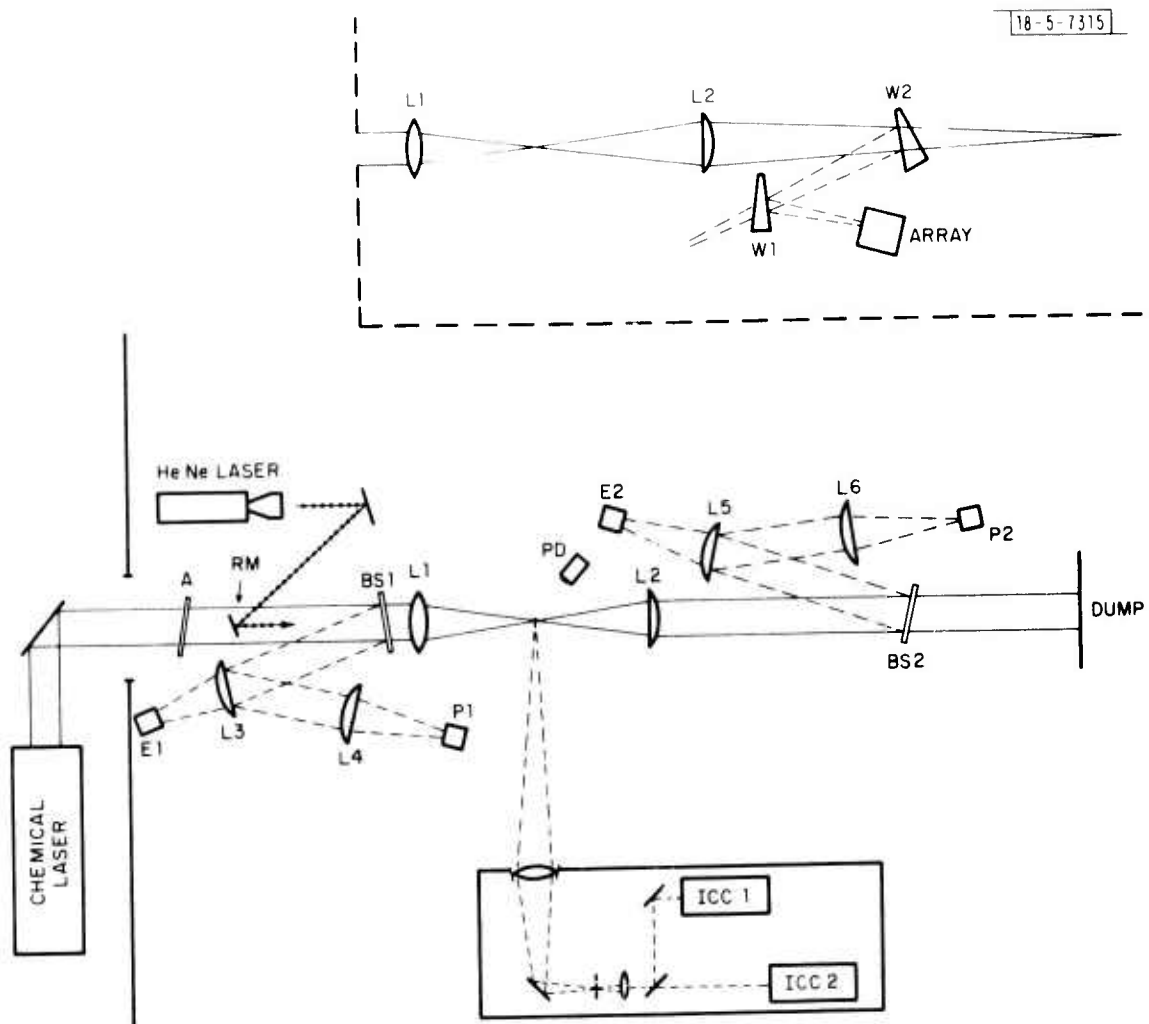


Fig. 1. Experimental set up for HF laser breakdown experiment. The focal volume of lens L1 was seeded with dust particles. The insert shows the arrangement for beam profile measurements.

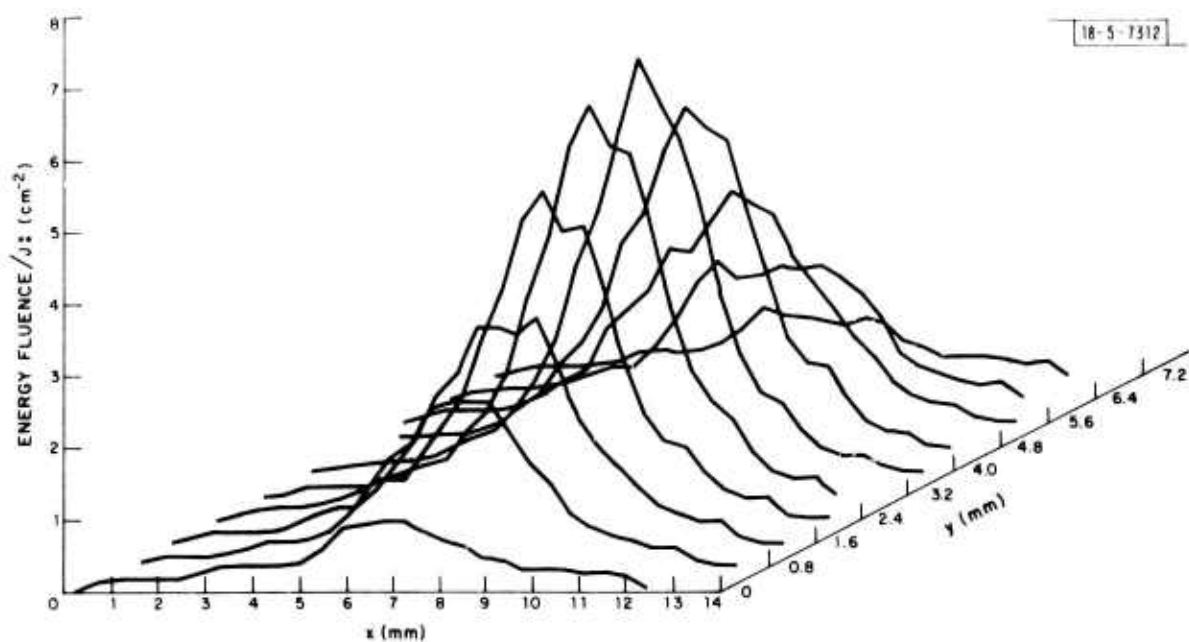
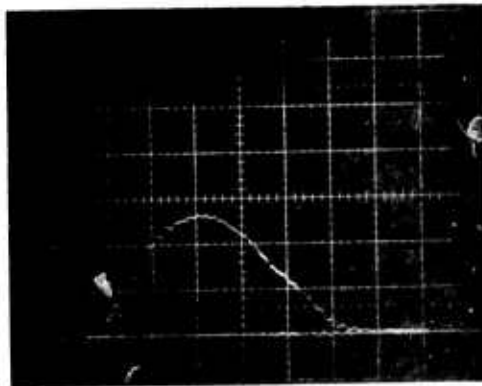


Fig. 2. Beam profile measured with pyroelectric array. The resolution was 0.4 mm in the x-direction and 0.8 mm in the y-direction.

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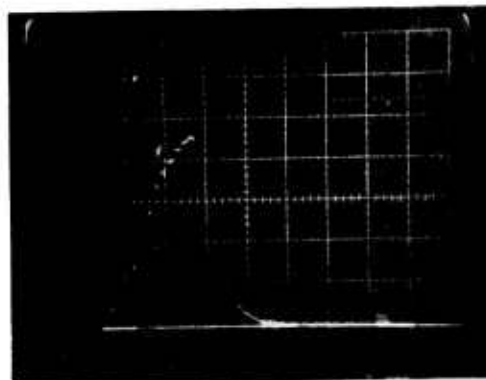
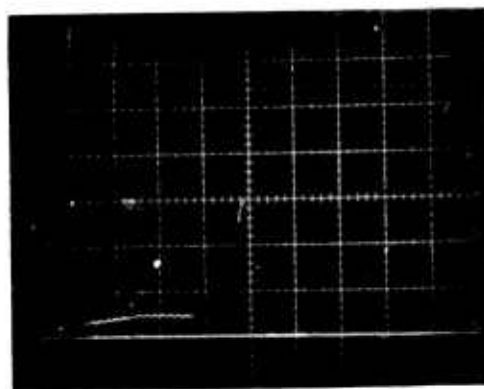


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Fig. 3. Oscillographs of: incident laser power, transmitted power, and light emitted from breakdown region.

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ESD-TR-76-313	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Air Breakdown Initiated by Particles in an HF Laser Beam	5. TYPE OF REPORT & PERIOD COVERED Project Report 09	
6. AUTHOR(s) Donald E. Lencioni, Lee C. Pettingill Donald P. DeGloria		6. PERFORMING ORG. REPORT NUMBER Project Report LTP-35
7. AUTHOR(s)		8. CONTRACT OR GRANT NUMBER(s) F19628-76-C-0002 ARPA Order-600
9. PERFORMING ORGANIZATION NAME AND ADDRESS Lincoln Laboratory, M. I. T. P. O. Box 73 Lexington, MA 02173		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS ARPA Order 600 Program Element No. 62301E Project No. 6E20
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced Research Projects Agency 1400 Wilson Boulevard Arlington, VA 22209		12. REPORT DATE 28 October 1976
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Electronic Systems Division Hanscom AFB Bedford, MA 01731		13. NUMBER OF PAGES 18 13716p
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES None		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) air breakdown HF laser 10 to the 7th power laser pulse length microsec. micrometers		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Thresholds were measured for air breakdown initiated by particles in a 3.5 μ sec, 2.9 μ m laser beam. The pulsed chemical laser at Boeing Aerospace Corporation was used for these studies. The thresholds for 50 μ m diameter graphite, NaCl, Al ₂ O ₃ particles and 10 μ m and 30 μ m quartz fibers were found to be factors of three to five higher than the comparable thresholds for 10.6 μ m lasers. The material dependence for the threshold was found to differ from that for short pulse 10.6 μ m breakdown. The radial plasma growth rate was measured and found to be approximately equal to the growth rate at 10.6 μ m for an intensity of 3×10^7 W/cm ² . SQ. CM 207 650		